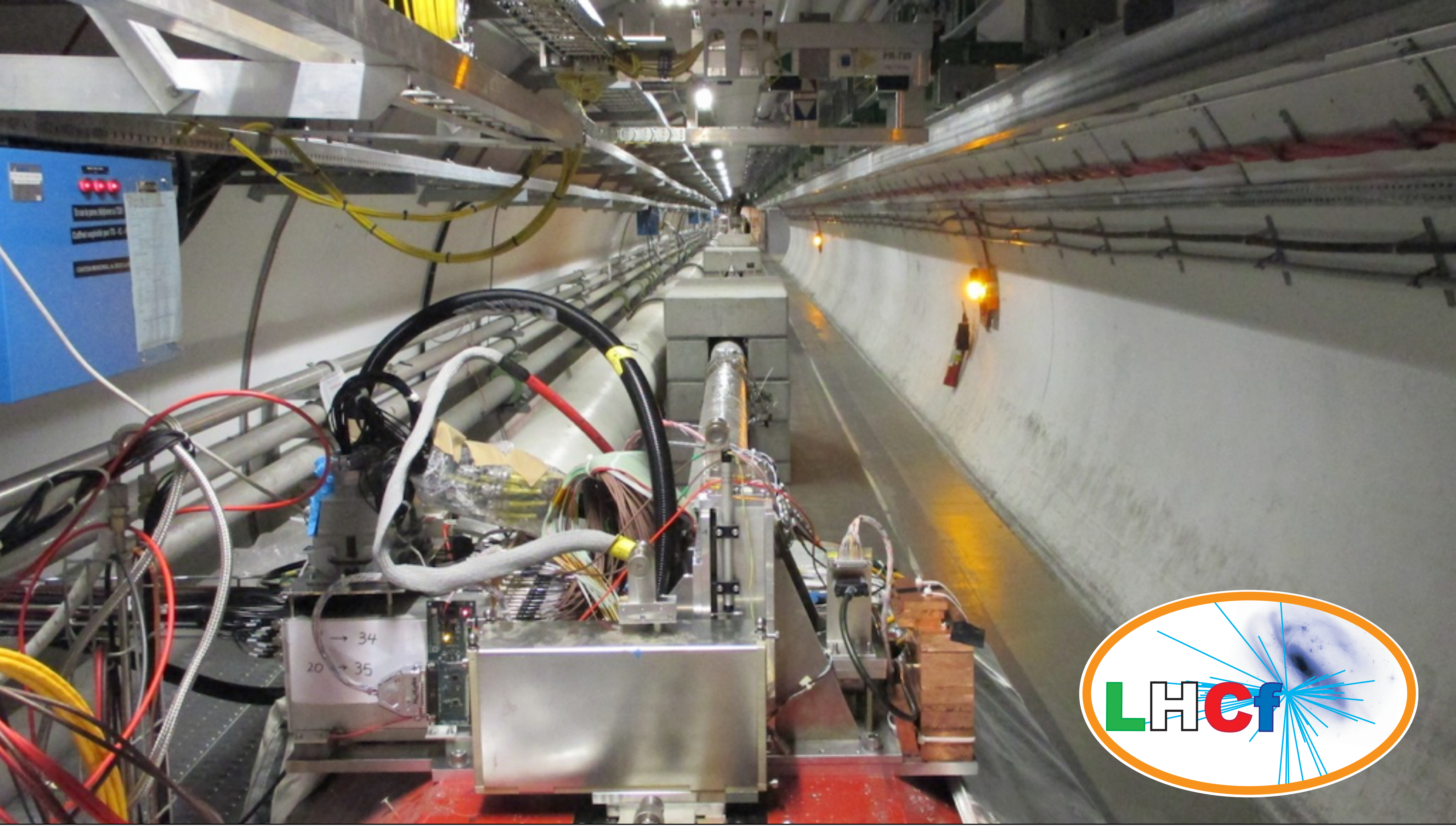

Large Hadron Collider forward (LHCf)
実験の概要とこれまでの測定結果

牧野 友耶
名古屋大学 CR研
YMAP若手研究会, ICRR

- UHECRs観測とハドロン相互作用モデル起因の不定性
- Large Hadron Collider forward (LHCf) 実験
- これまでの測定結果(p-p/p-Pb, √s=900 GeV - 7 TeV)
- 新型検出器開発
- 13 TeV測定とPreliminary results

Large Hadron Collider forward (LHCf) 実験の概要とこれまでの測定結果

牧野 友耶
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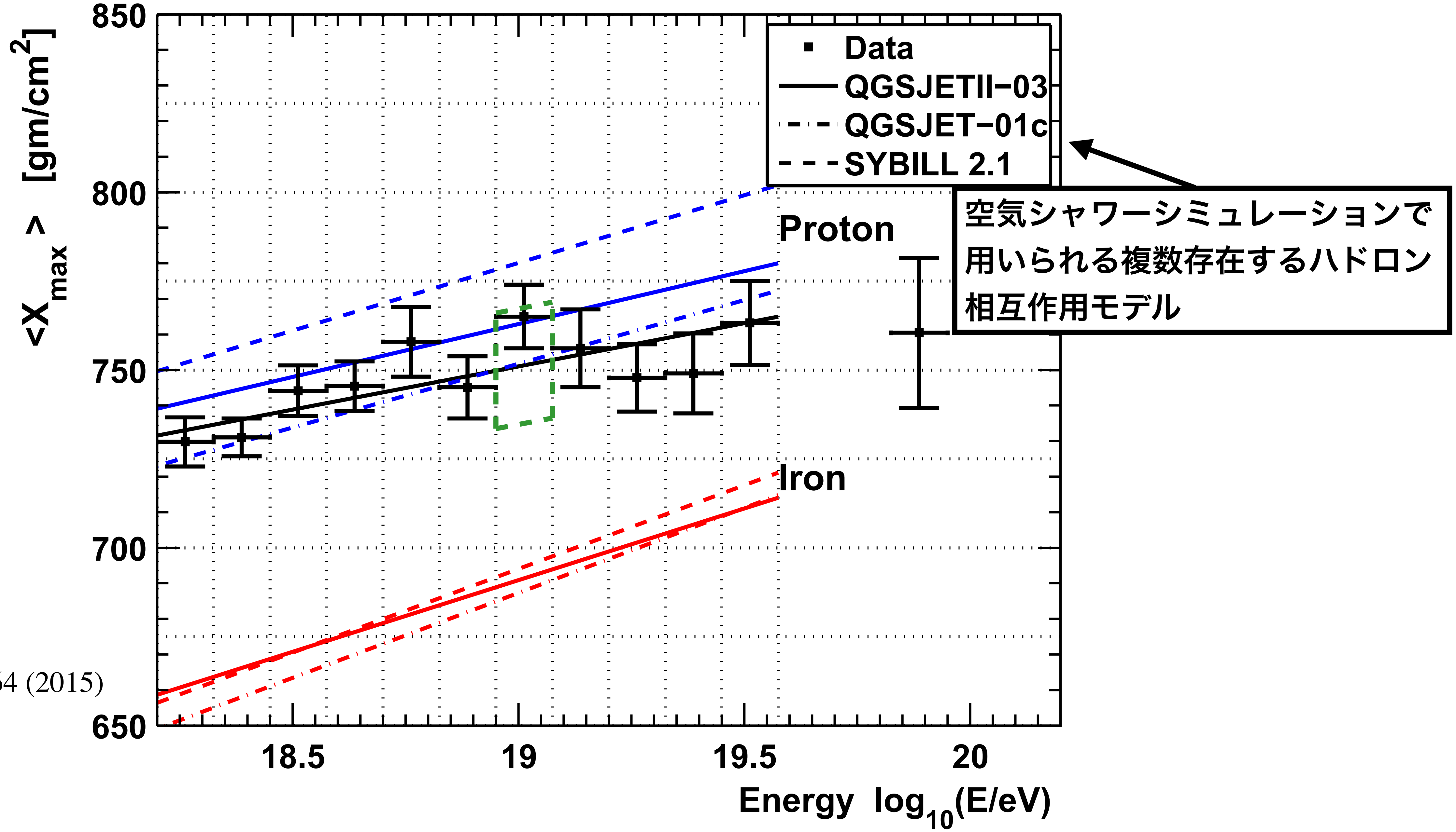
UHECRとハドロン相互作用モデルの問題

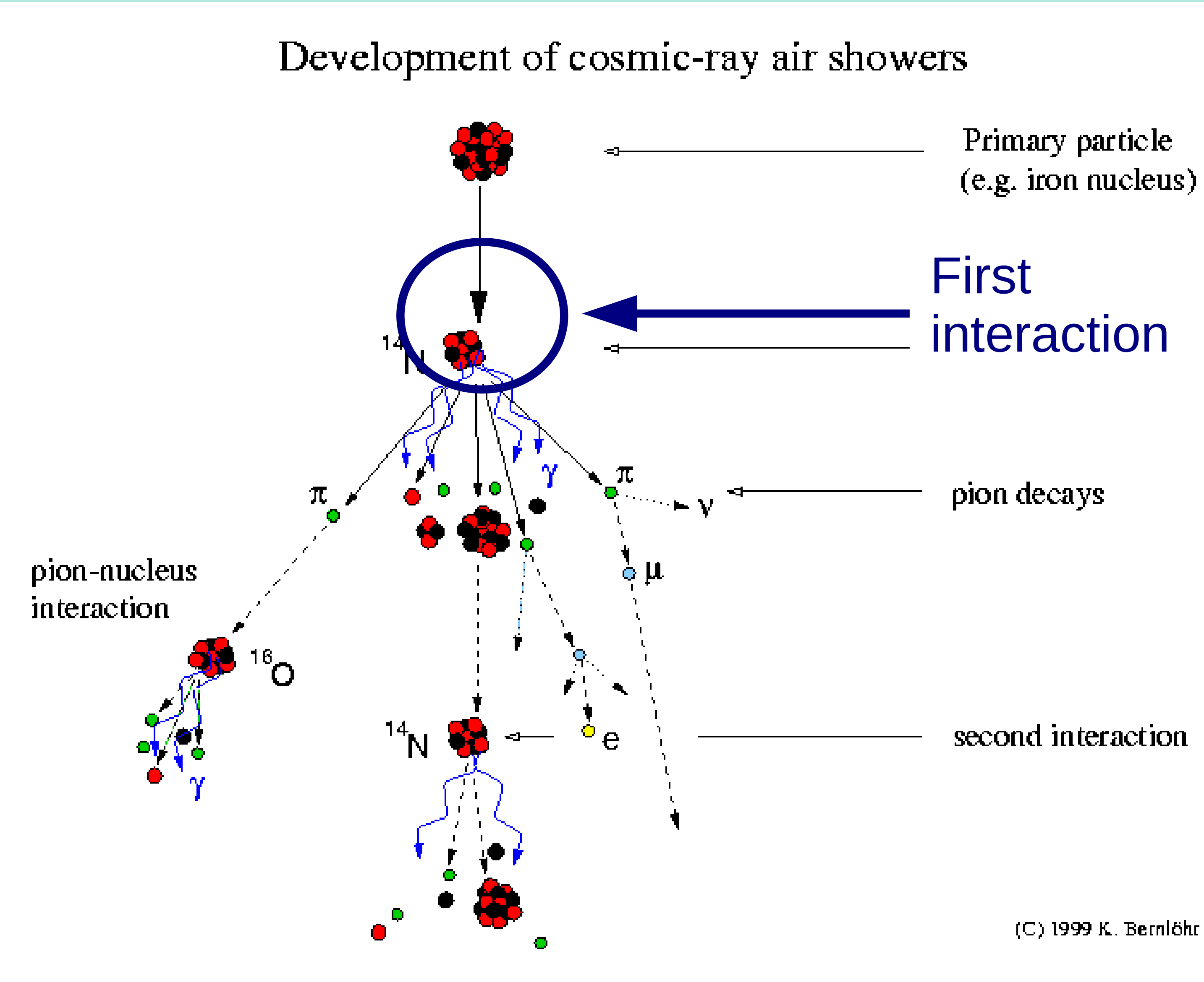


R.U. Abbasi et al.,

Astroparticle Physics 64 (2015)

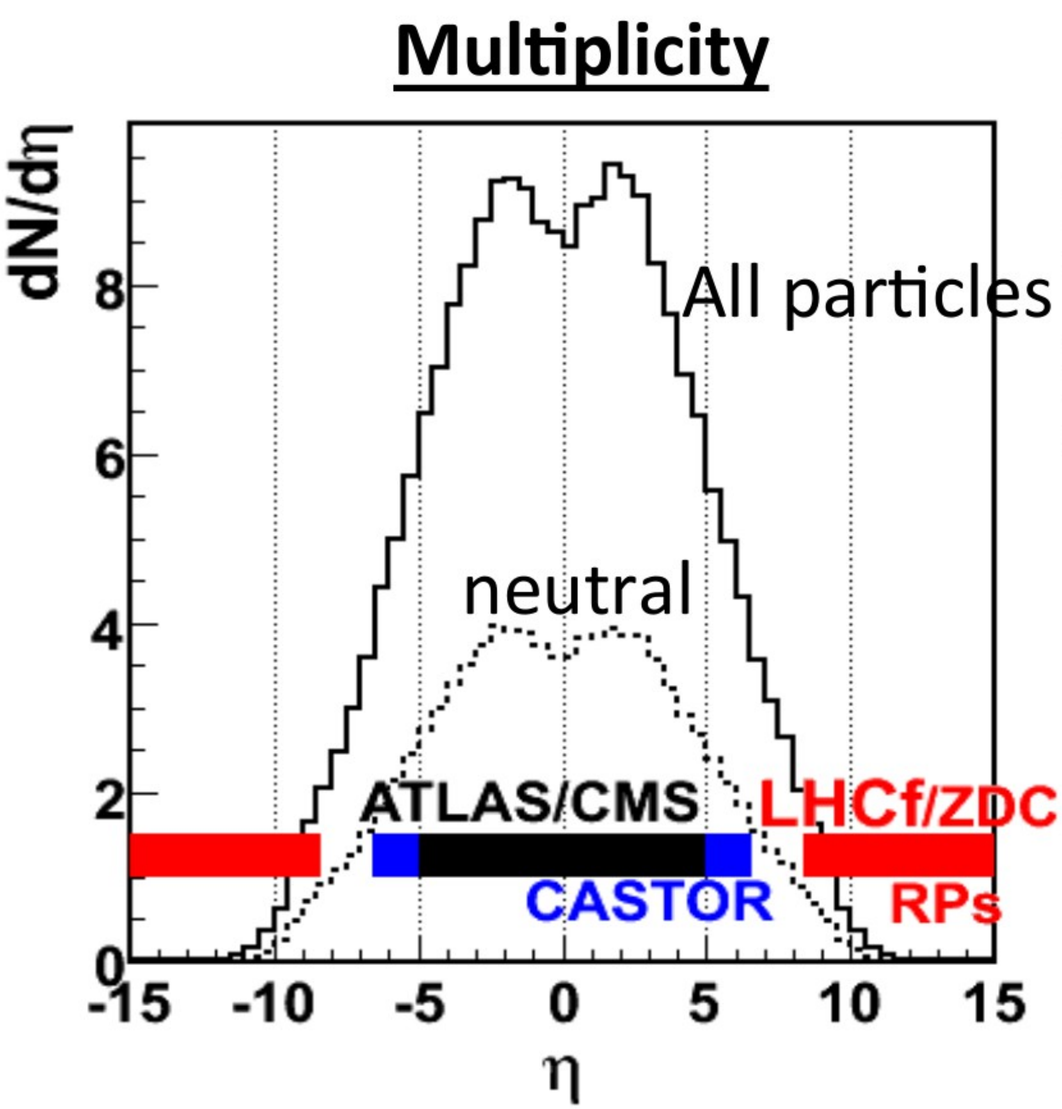
- 空気シャワー実験がUHECRsの観測数を増やしつつある
  - TAx4, Auger primeによりさらに高統計が期待
- 相互作用モデル起因の不定性が化学組成決定のボトルネック

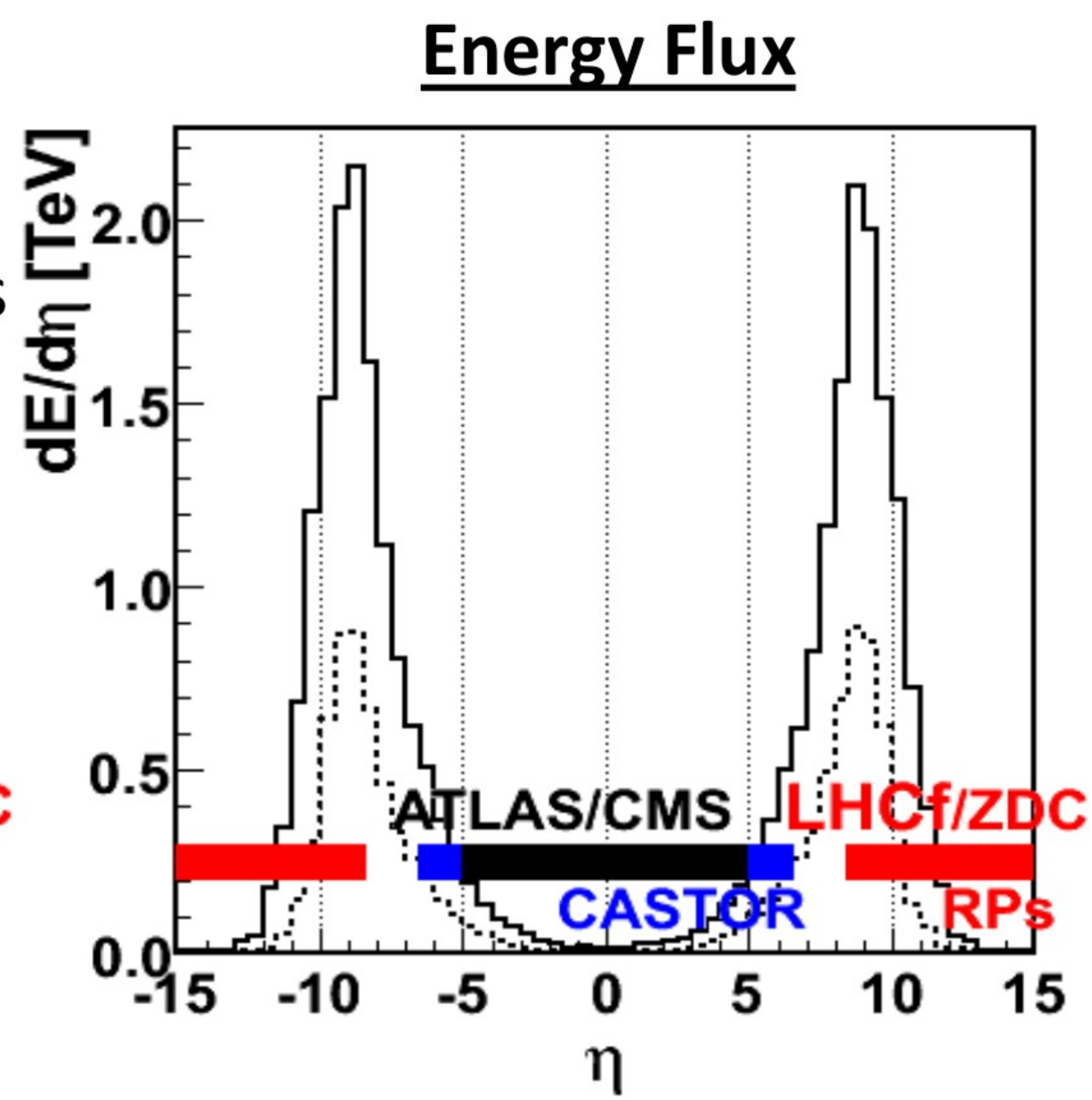
Contributions from accelerator experiments



- **Inelastic cross section** (by TOTEM)
  large → rapid development
  small → deep penetrating
- **Inelasticity $k = 1 - p_{lead} / p_{mean}$** neutrons
  large → rapid development
  small → deep penetrating
- **Forward energy spectrum** photons, π^0
  softer → rapid development
  harder → deep penetrating
- **Nuclear effects** p-Pb collisions
- **Extrapolation to high energies**
  precise measurements at lower energies are crucial
  many data points

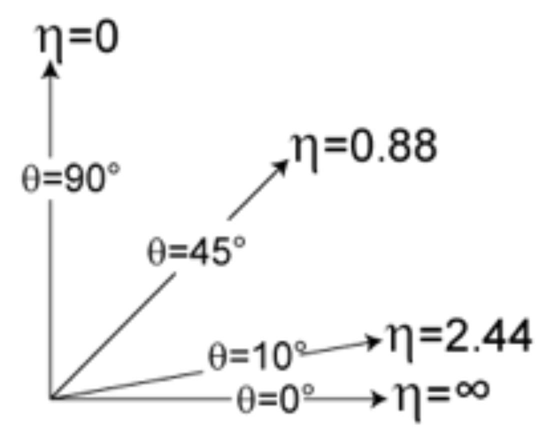
相互作用モデルの加速器実験による検証





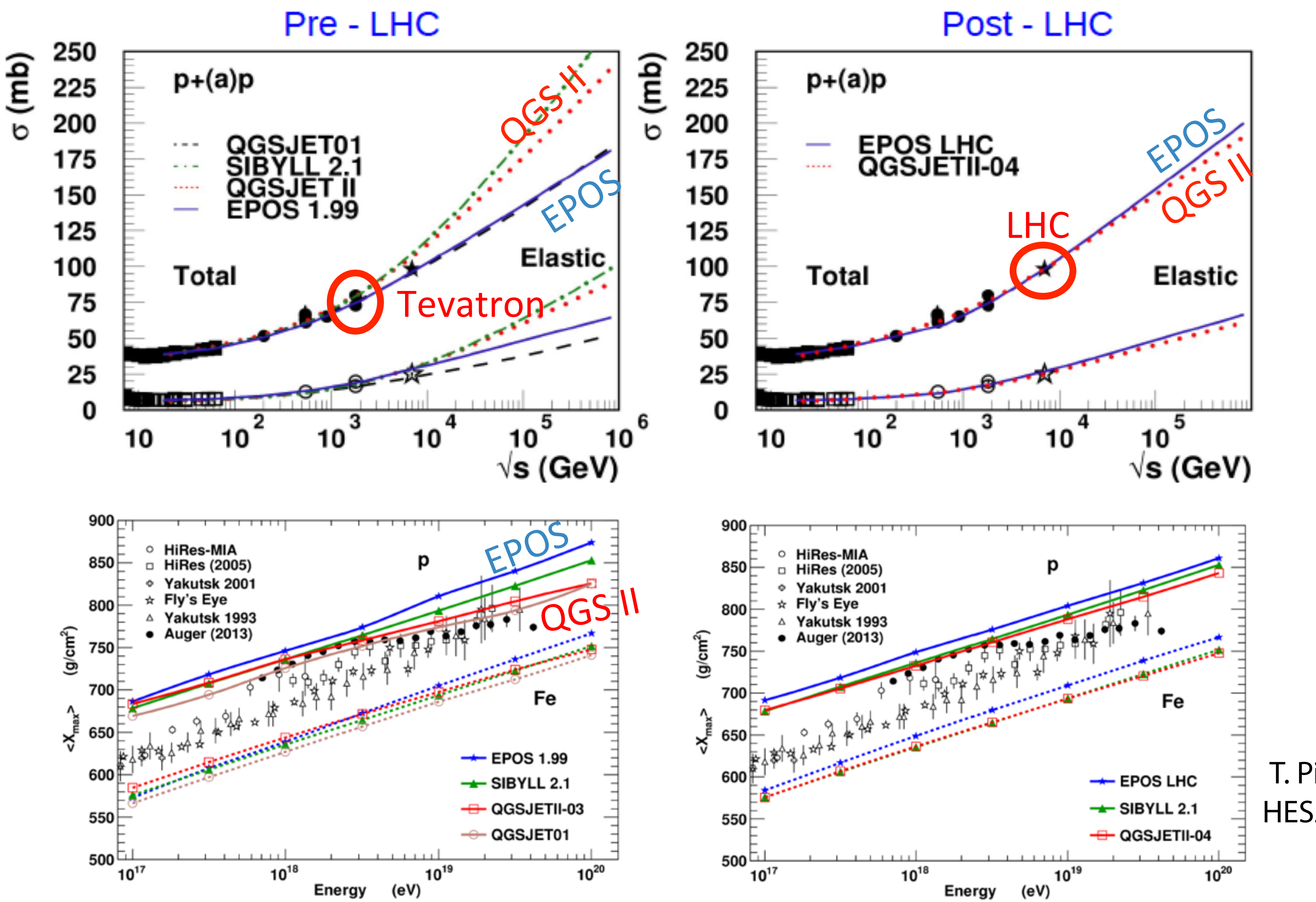
Pseudo-rapidity

$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



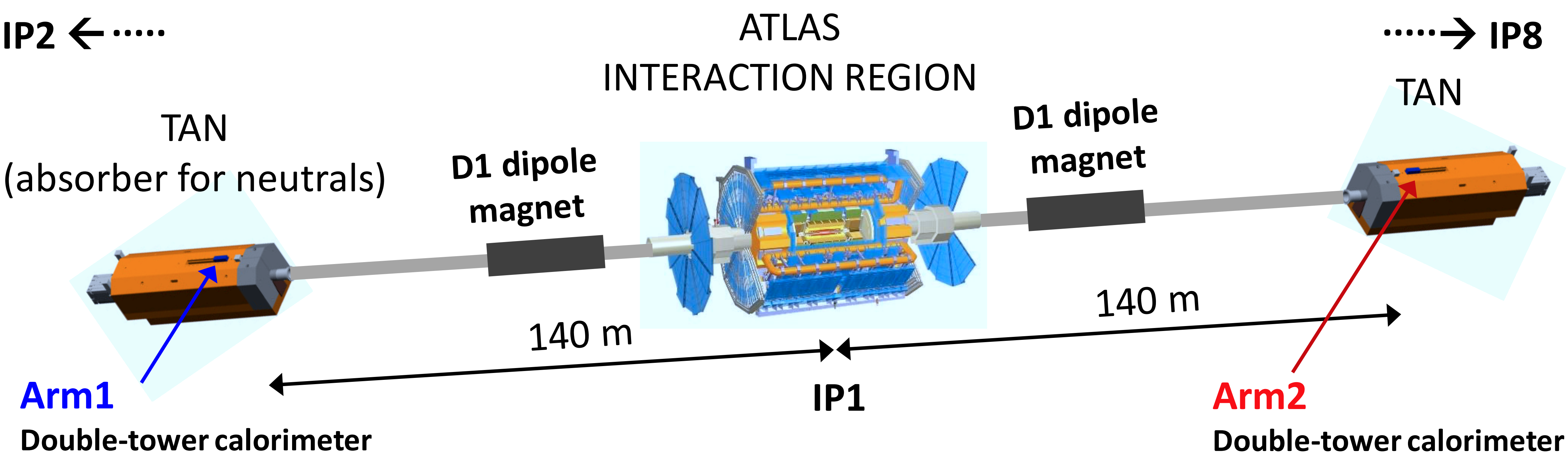
- 空気シャワー発達に関連するのは、エネルギー流量の大きい(超)前方領域
- 前方での粒子生成を測定し、相互作用モデルの予測と比較する

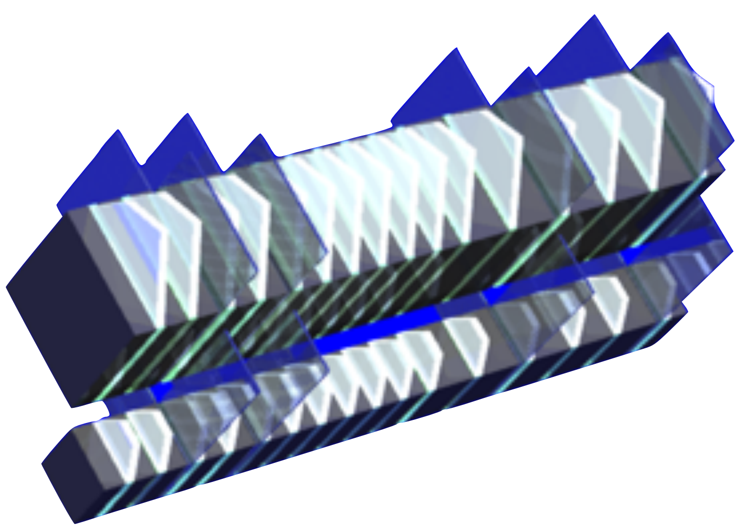
LHCによる成果：post-LHC models



T. Pierog, HESZ2015

The Large Hadron Collider forward (**LHCf**) experiment



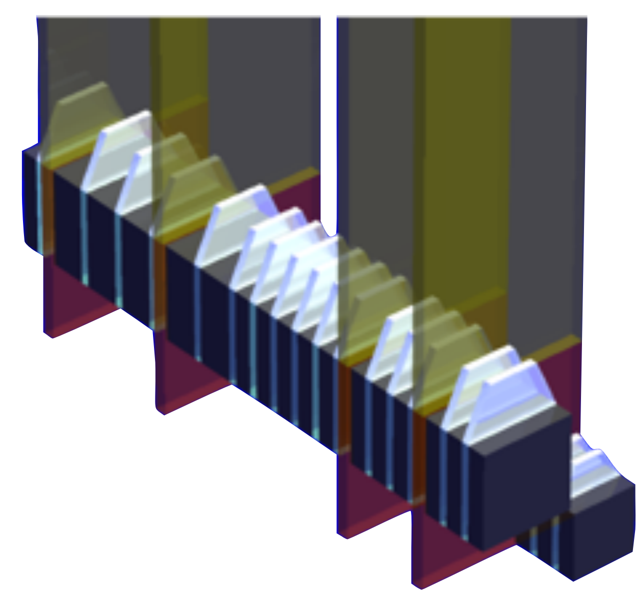


- 4 X-Y **SciFi** imaging layers + MAPMTs
- 20mm x 20mm + 40mm x 40mm

- **Sampling & Imaging E.M. calorimeters**
  2 calorimeter towers
  Absorber: Tungsten **$44X_0$, 1.6 λ_{int}**
  Energy measurement: 16 plastic scintillator tiles
  Imaging: 4 tracking layers

Performance

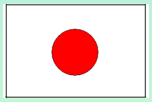
- Energy resolution (>100GeV)
  5% for γ, 40% for neutron
- Position resolution (E.M shower)
  < 200 μm (#Arm1)
  ~ 40 μm (#Arm2)



- 4 X-Y **Silicon strip** imaging layers
- 25mm x 25mm + 32mm x 32mm

The LHCf collaboration

The LHCf Collaboration



[*,]Y.Itow, [*]Y.Makino, [*]K.Masuda, [*]Y.Matsubara, [*]E.Matsubayashi, [***]H.Menjo, [*]Y.Muraki, [*,**]T.Sako, [*]K.Sato, [*] M.Shinoda, [*]M.Ueno, [*]Q.D.Zhou**

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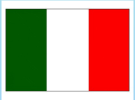
M.Haguenauer *Ecole Polytechnique, France*

W.C.Turner *LBNL, Berkeley, USA*



O.Adriani, E.Berti, L.Bonechi, M.Bongi, G.Castellini, R.D'Alessandro, P.Papini, S.Ricciarini, A.Tiberio
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2

The LHCf collaboration

The LHCf Collaboration

student

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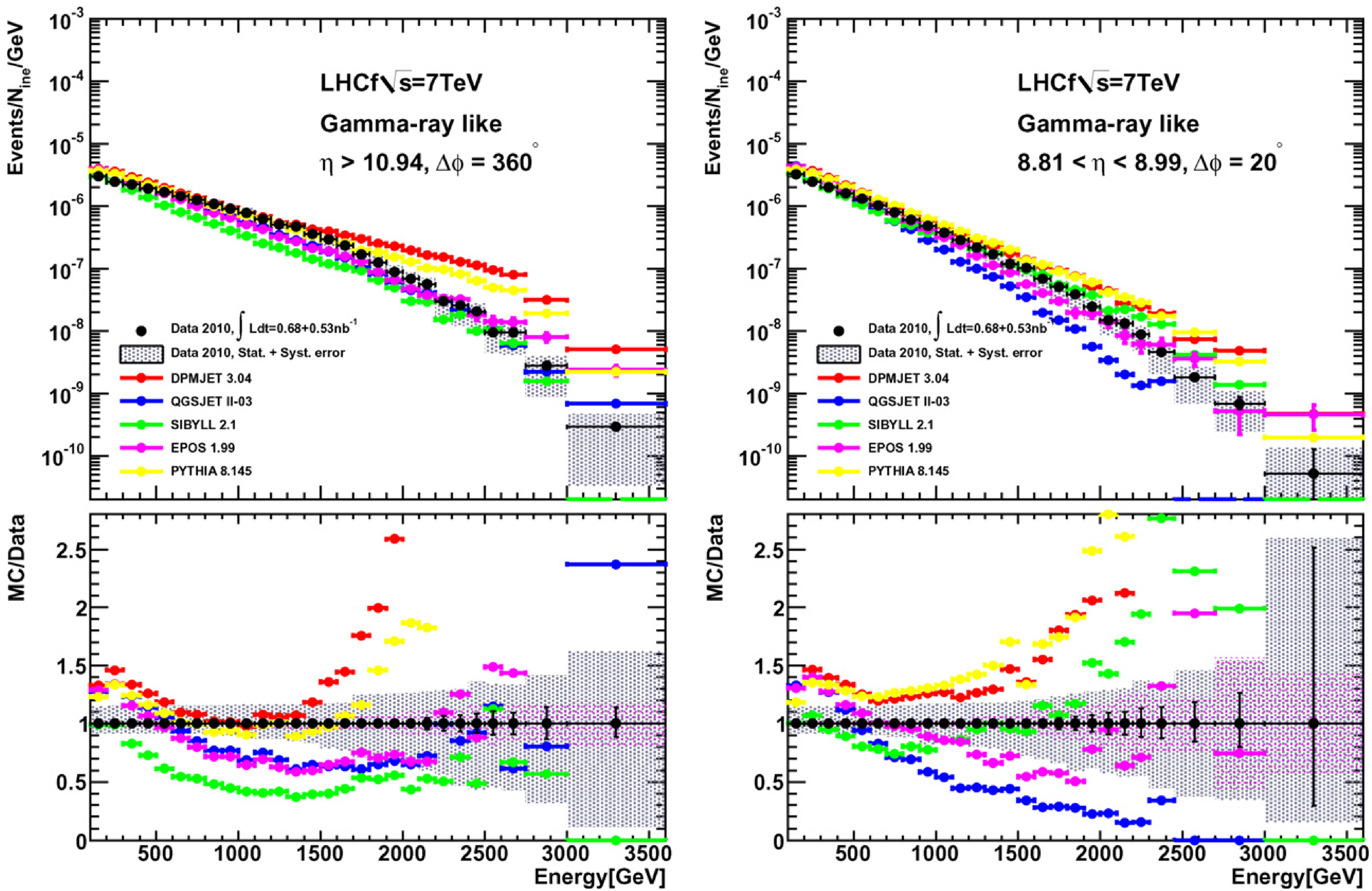
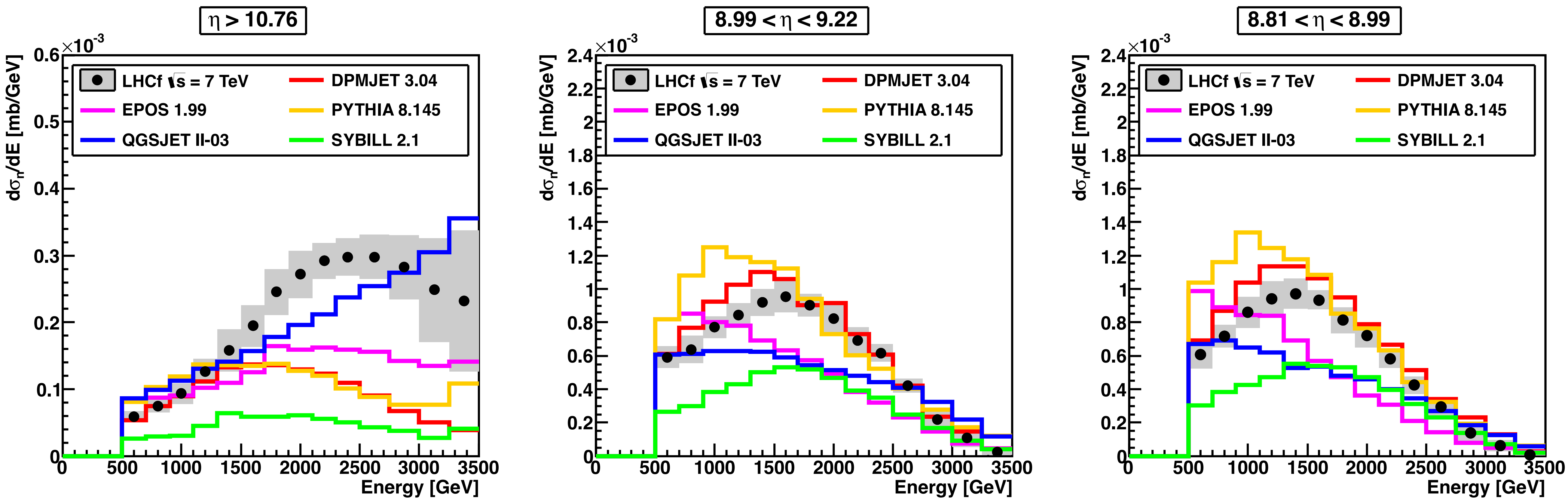
2

Photon energy spectra @ $\sqrt{s}$ = 7TeV



- No model can reproduce LHCf spectra
  - but data points are among model predictions

Neutron spectra @ √s = 7 TeV



- Neutron production may be relevant to muon production
  - Could be a key for muon problem
- EPOS 1.99, QGSJETII-03, SIBYLL 2.1 were not able to reproduce measured spectra

Publications

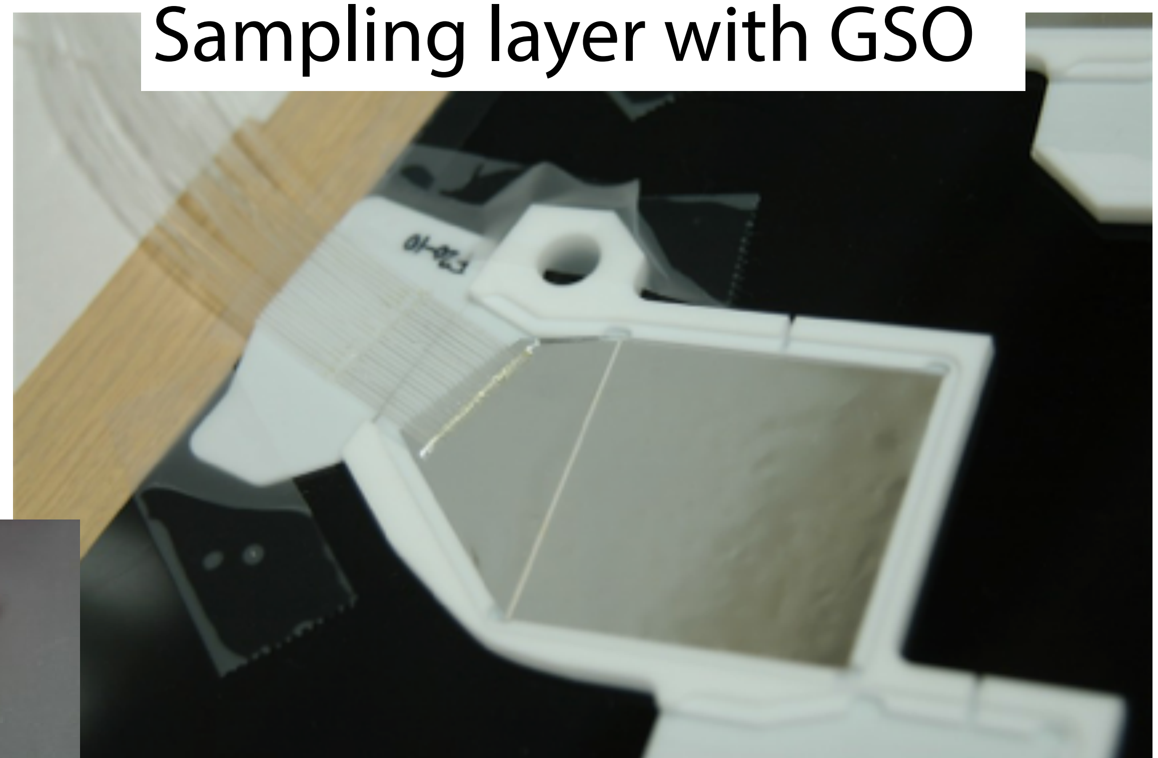
		Proton equivalent energy in lab (eV)	Gamma	Neutron	π^0
Former detector	Detector performance (old)	-	NIM A, 671, 129 (2012)	JINST 9 P030016 (2014)	-
	p+p $\sqrt{s}$ = 900GeV	$4.3\text{x}10^{14}$	Phys. Lett. B 715 298 (2012)		-
	p+p $\sqrt{s}$ = 7TeV	$2.6\text{x}10^{16}$	Phys. Lett. B 703, 128 (2011)	Phys. Lett. B 750 (2015) 360366	Phys. Rev. D 86, 092001 (2012) + Phys. Rev. C 89, 065029 (2014) + Phys. Rev. D 94 032007 (2016)
	p+p $\sqrt{s}$ = 2.76 TeV	$4.1\text{x}10^{15}$			
	p+Pb $\sqrt{s}$ = 5.02 TeV	$1.4\text{x}10^{16}$			
Upgraded detector	**Detector performance (new)**	-	**to be submitted (JINST)**		-
	p+p $\sqrt{s}$ = 13 TeV	10^{17}	**Analysis completed, paper writing**	Next target	

New rad-hard LHCf detectors for √s=13 TeV

LHCf検出器の設置場所はLHCの中でも放射線環境が過酷なところ。

特に13 TeV測定では30 Gy/nb^{-1}に達し、プラシン等では正確な測定が無理

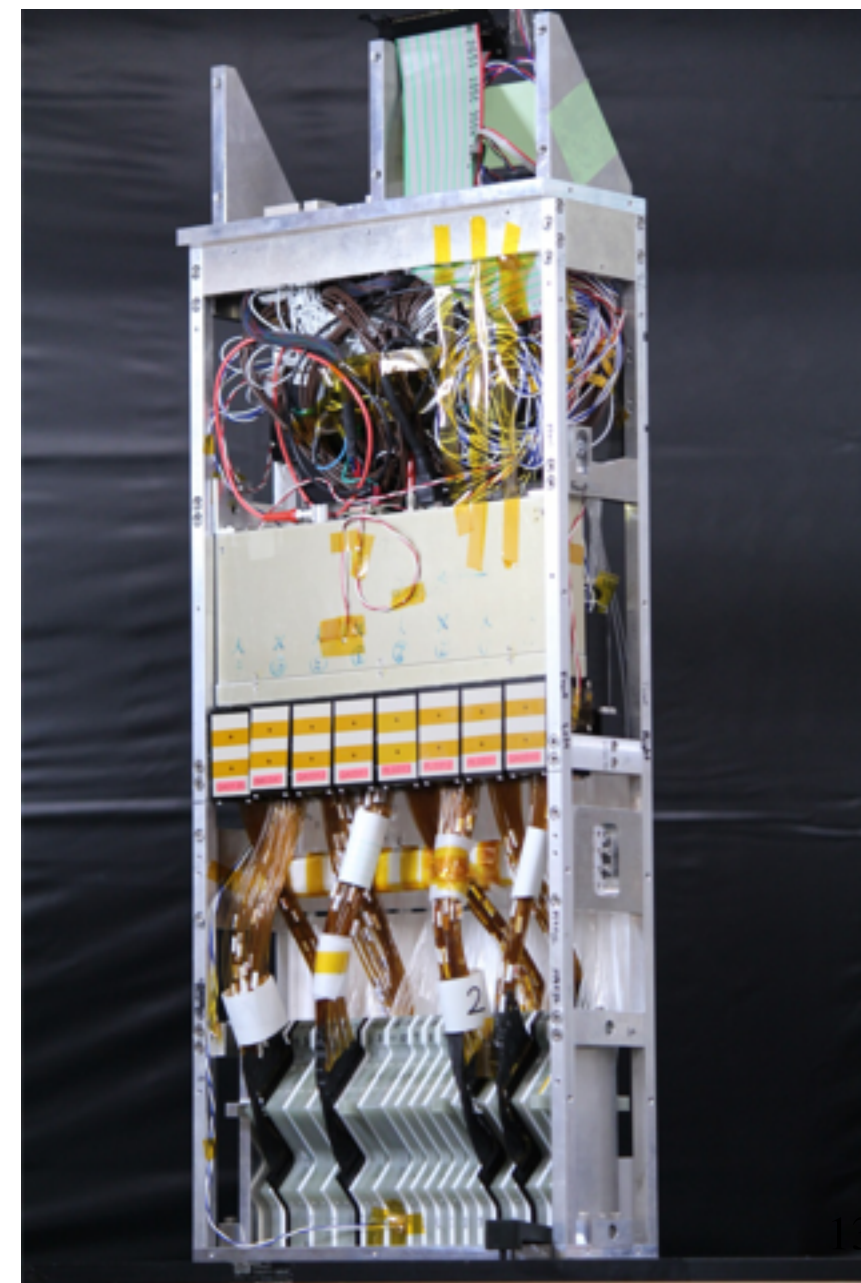
カロリメータと位置検出器SciFiで使用していた、プラシンをGd_2SiO_5 (GSO)に変更



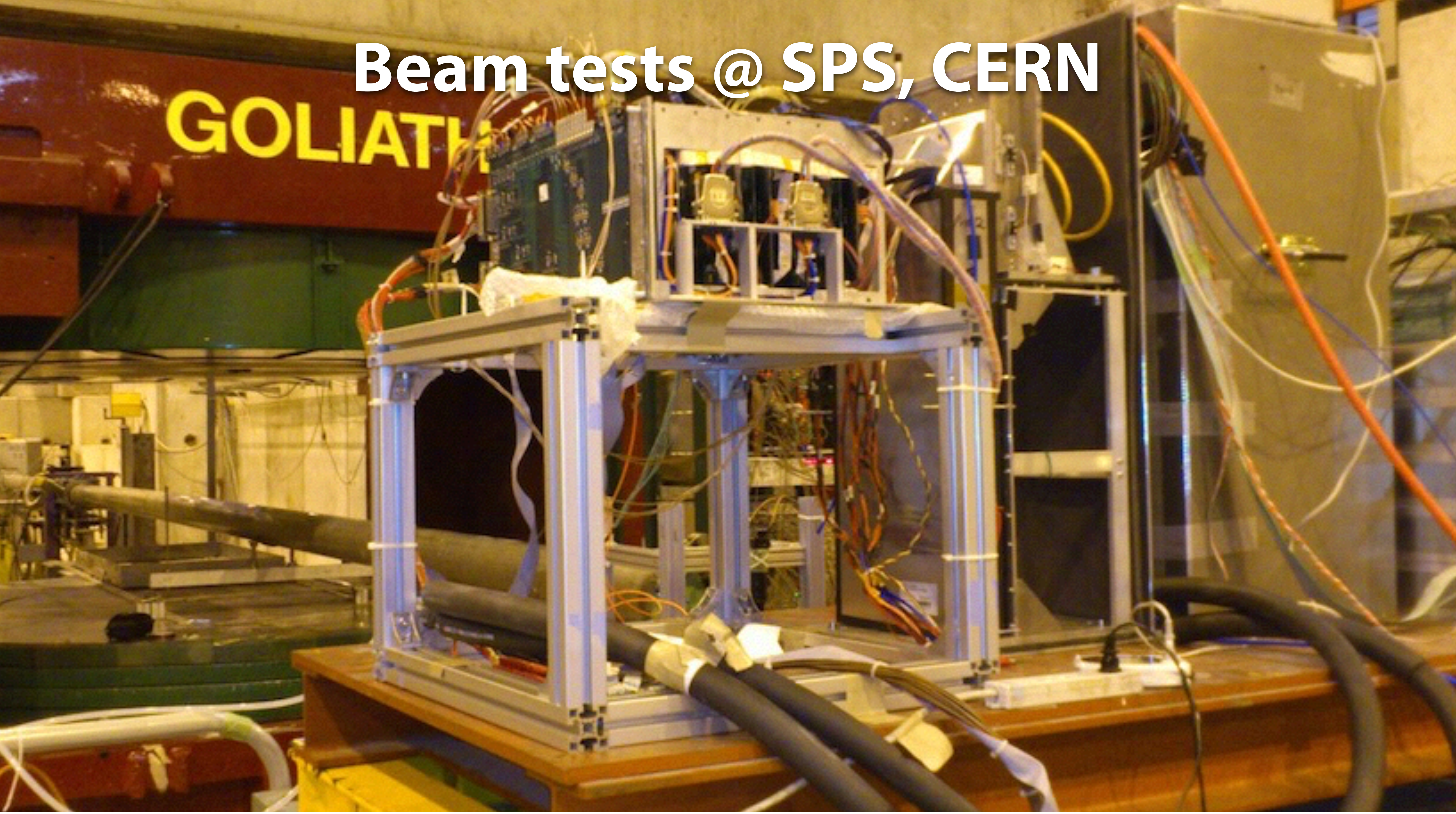
Sampling layer with GSO

GSO-bar hodoscope

X-Y井桁状に並べた1mm pitchのGSOシンチレータからなるシャワー位置検出器

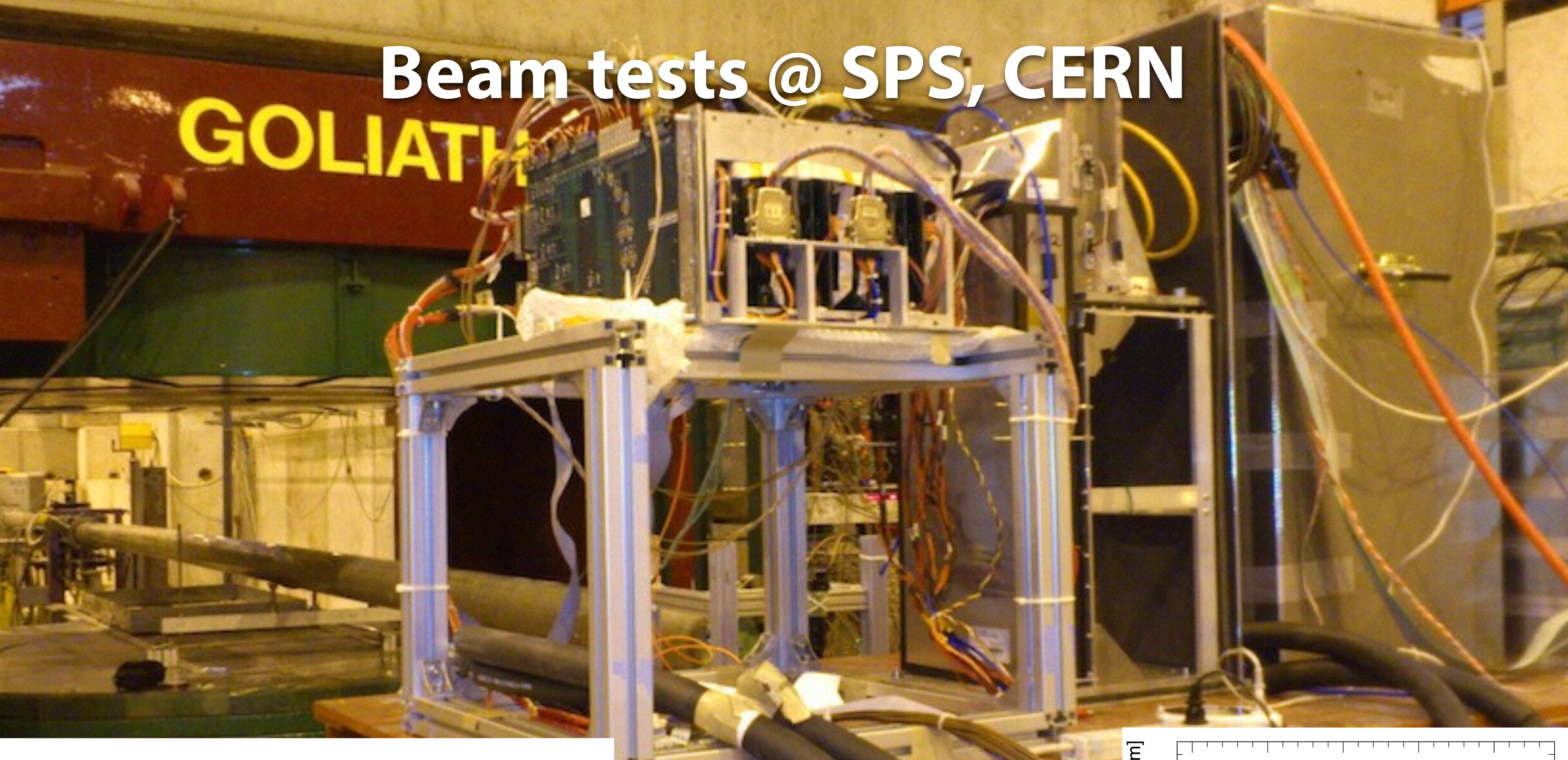


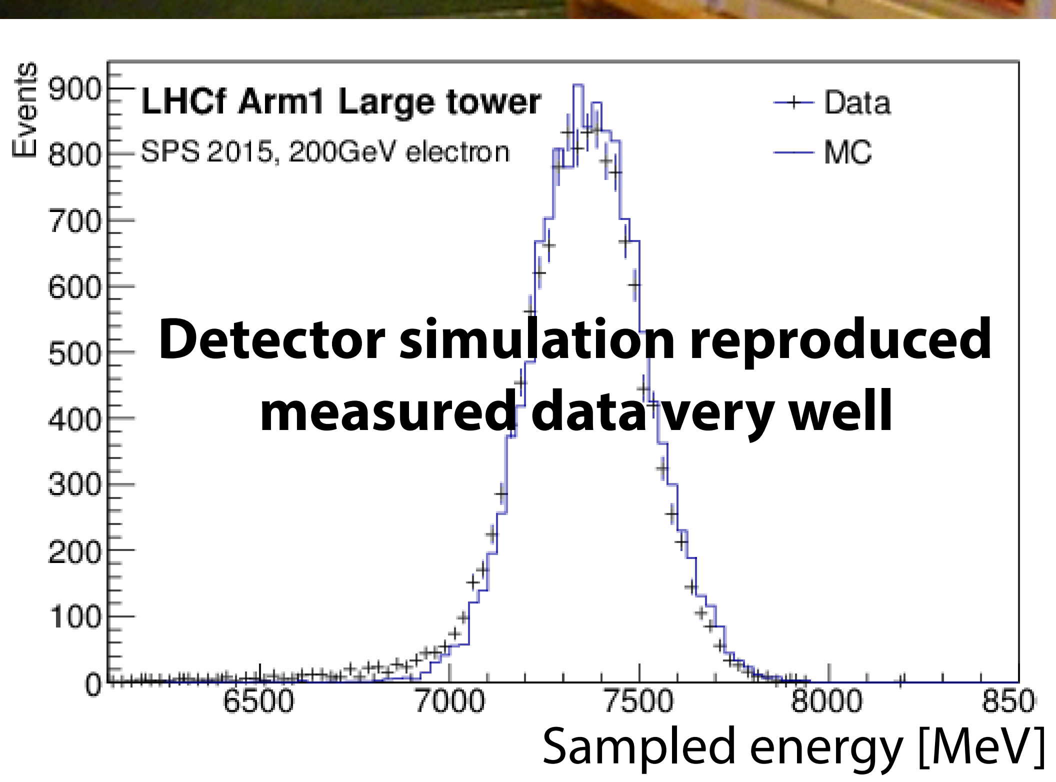
Beam tests @ SPS, CERN

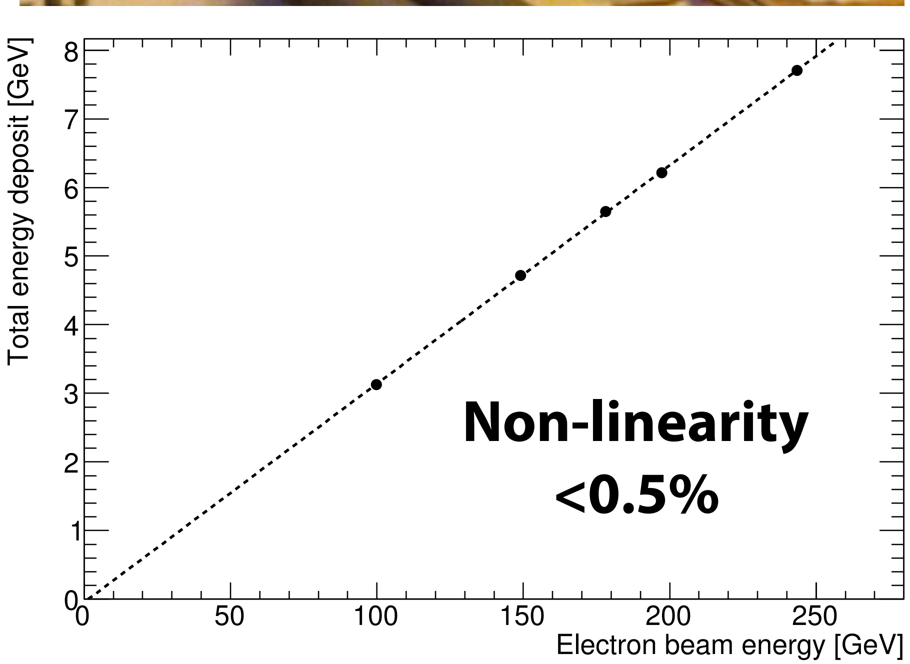


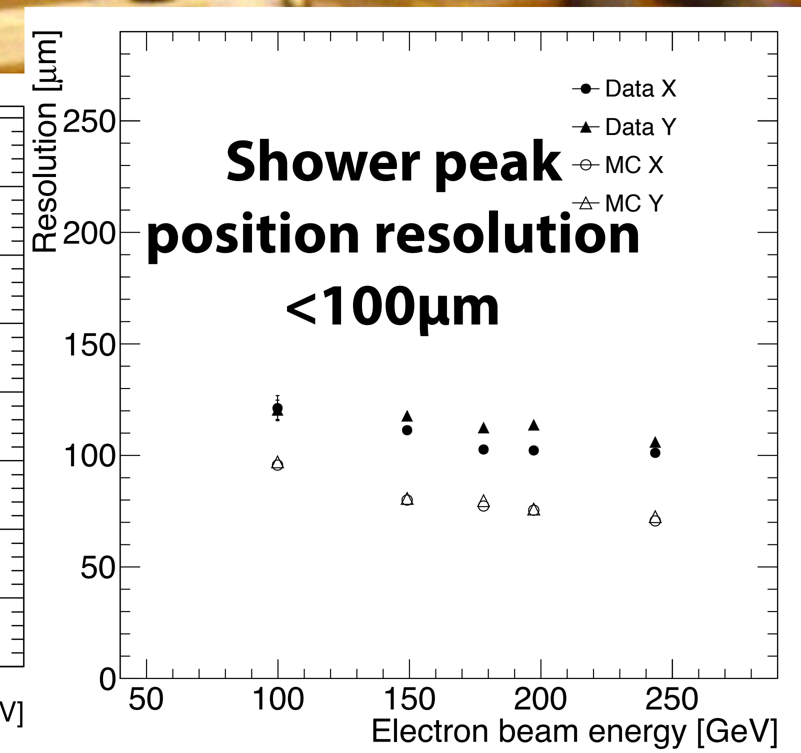
- 2012/2014/2015の3回実施
- 100-250 GeV electron/muon, 200-350 GeV protonを使用
  - $\sqrt{s}$=13 TeVで測定するのは $200 < E < 6500$ GeV
- 検出器のcalibration & performance check

Beam tests @ SPS, CERN

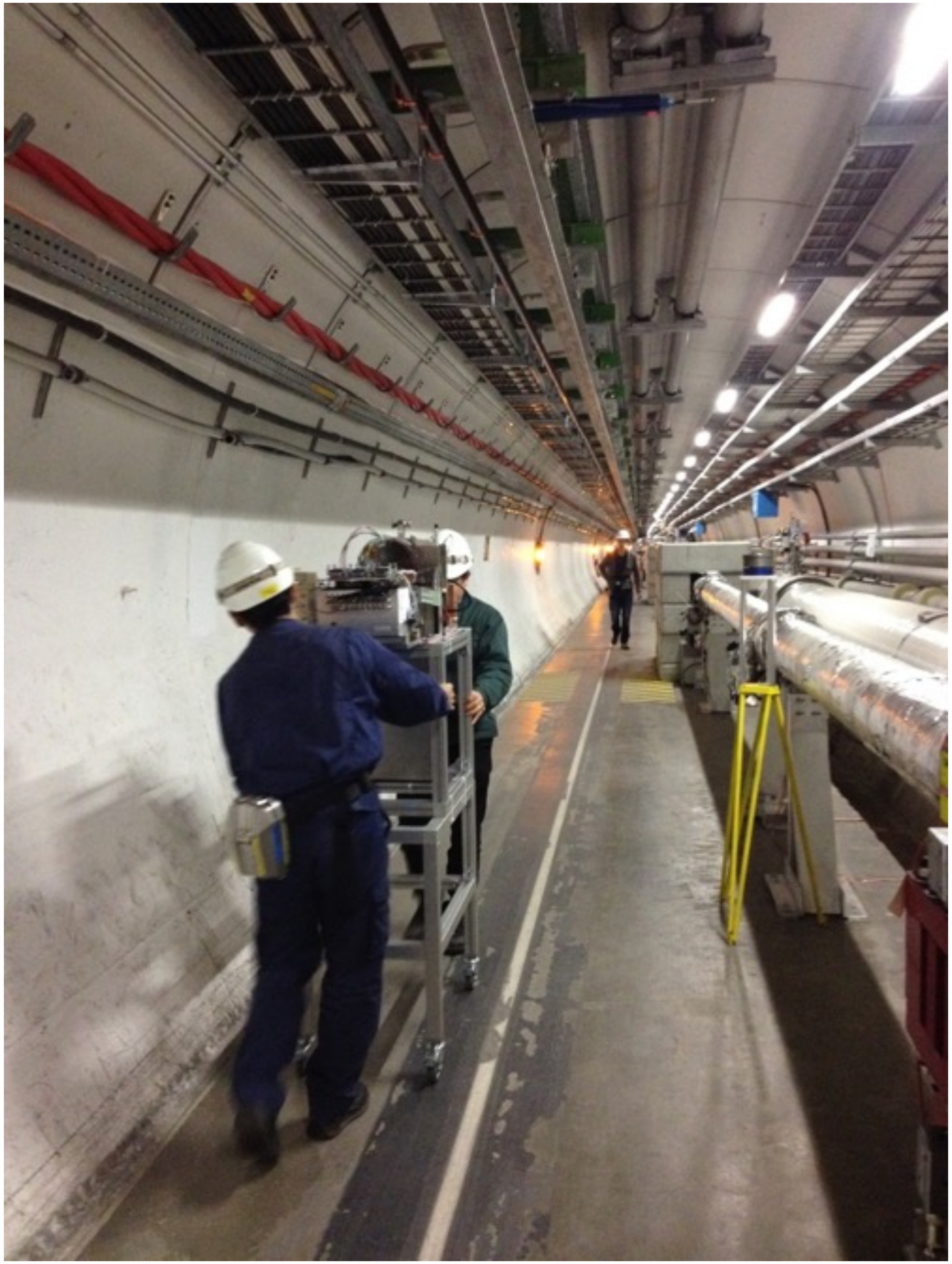


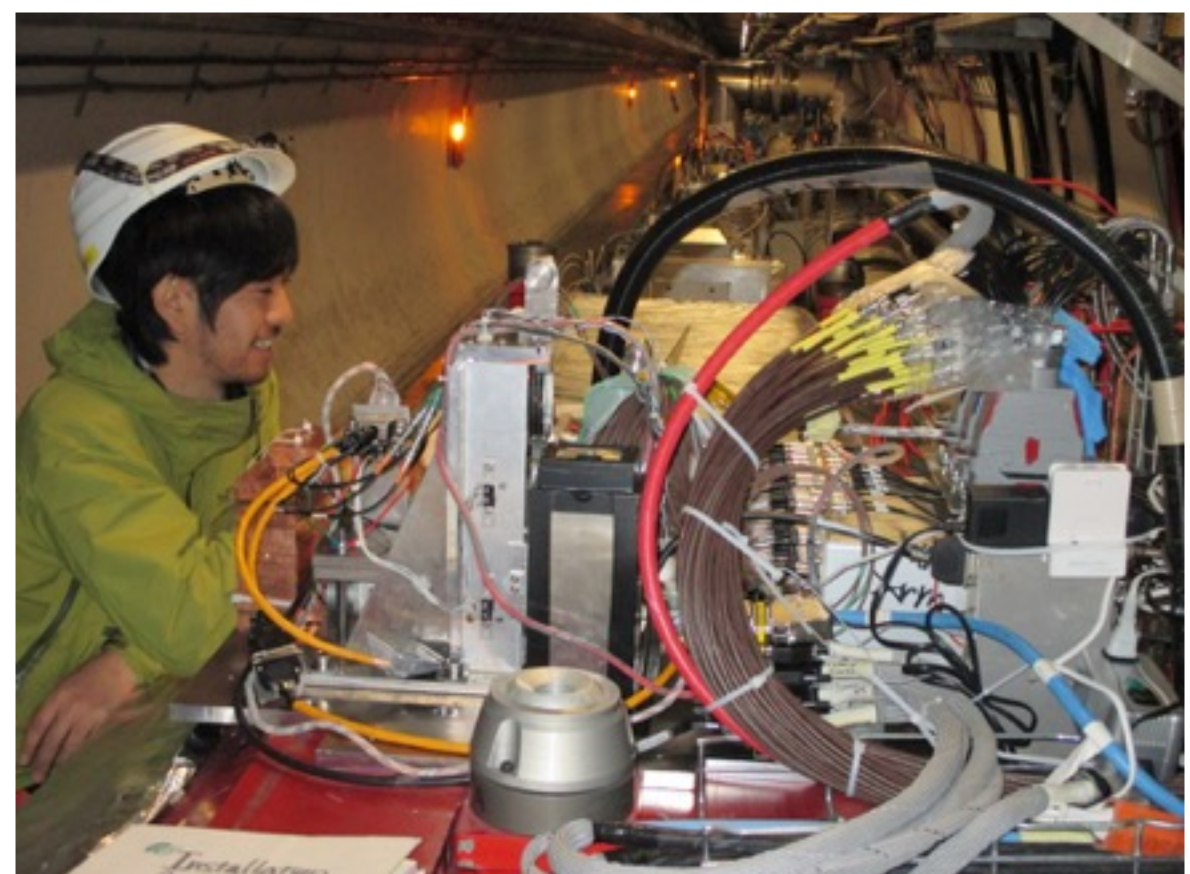


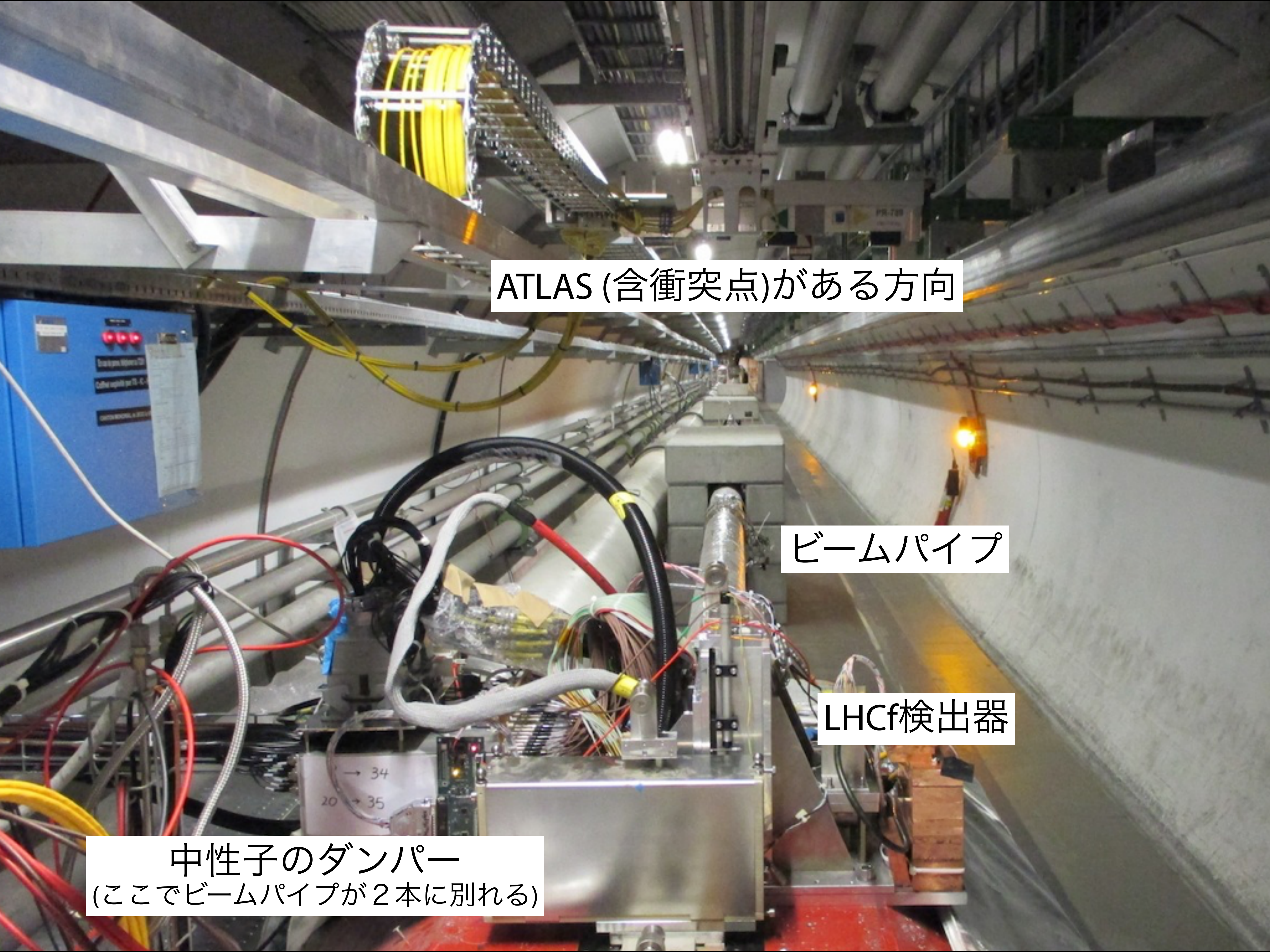




Installation (Nov. 2014)

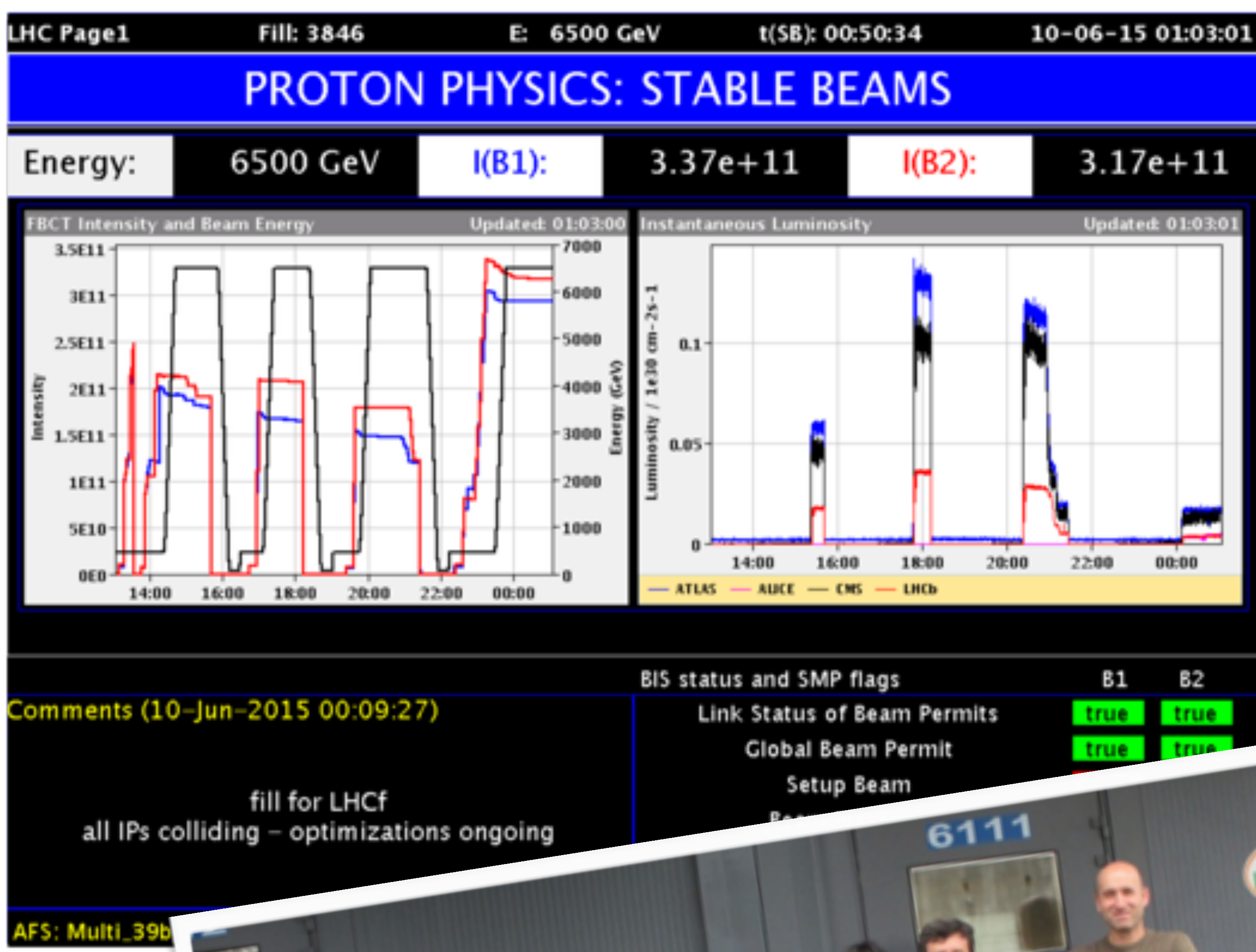





ATLAS (含衝突点)がある方向
ビームパイプ
LHCf検出器
中性子のダンパー
(ここでビームパイプが２本に別れる)

“LHCf dedicated run” in p-p √s=13TeV, 2015

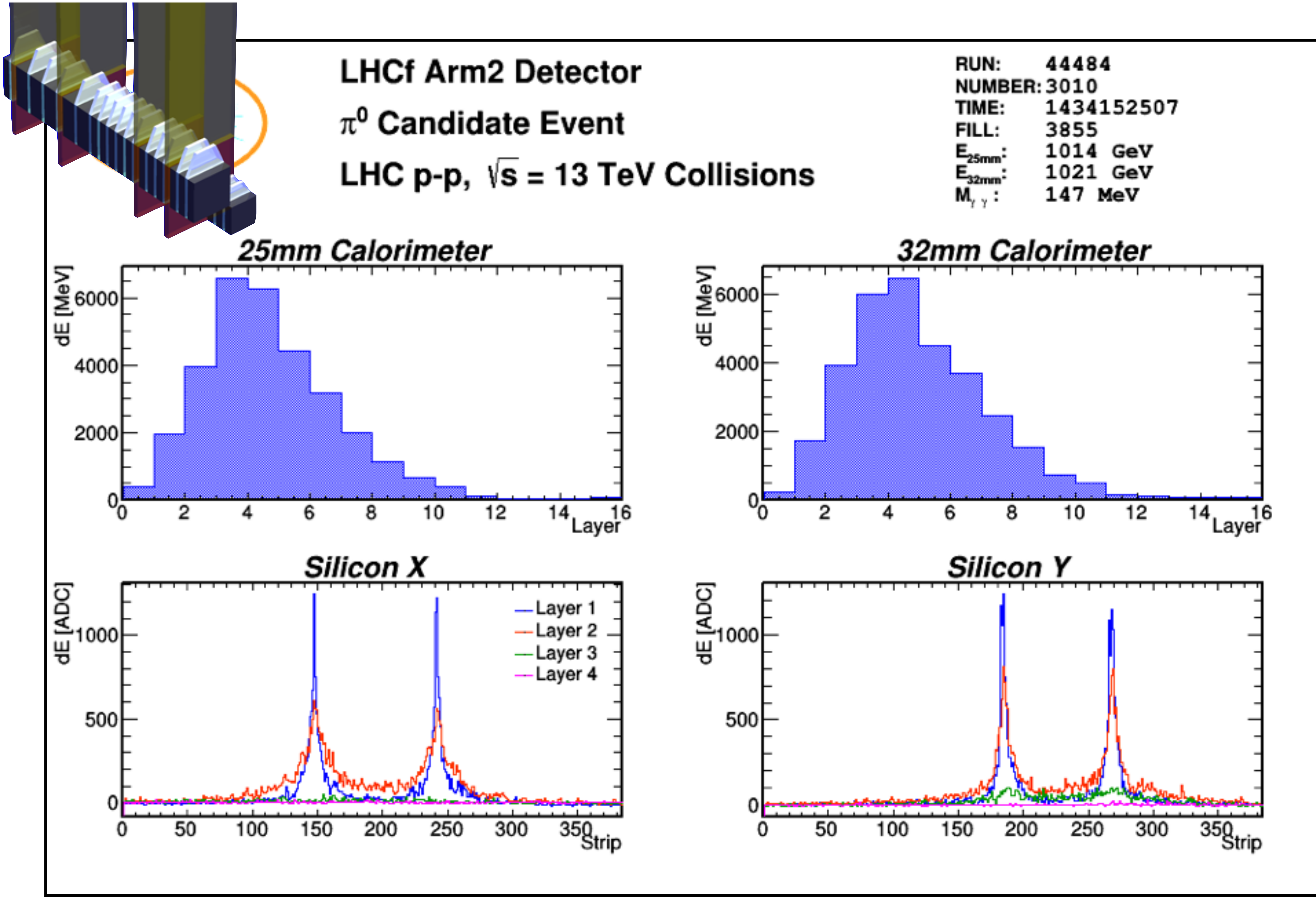
LHCf dedicated run



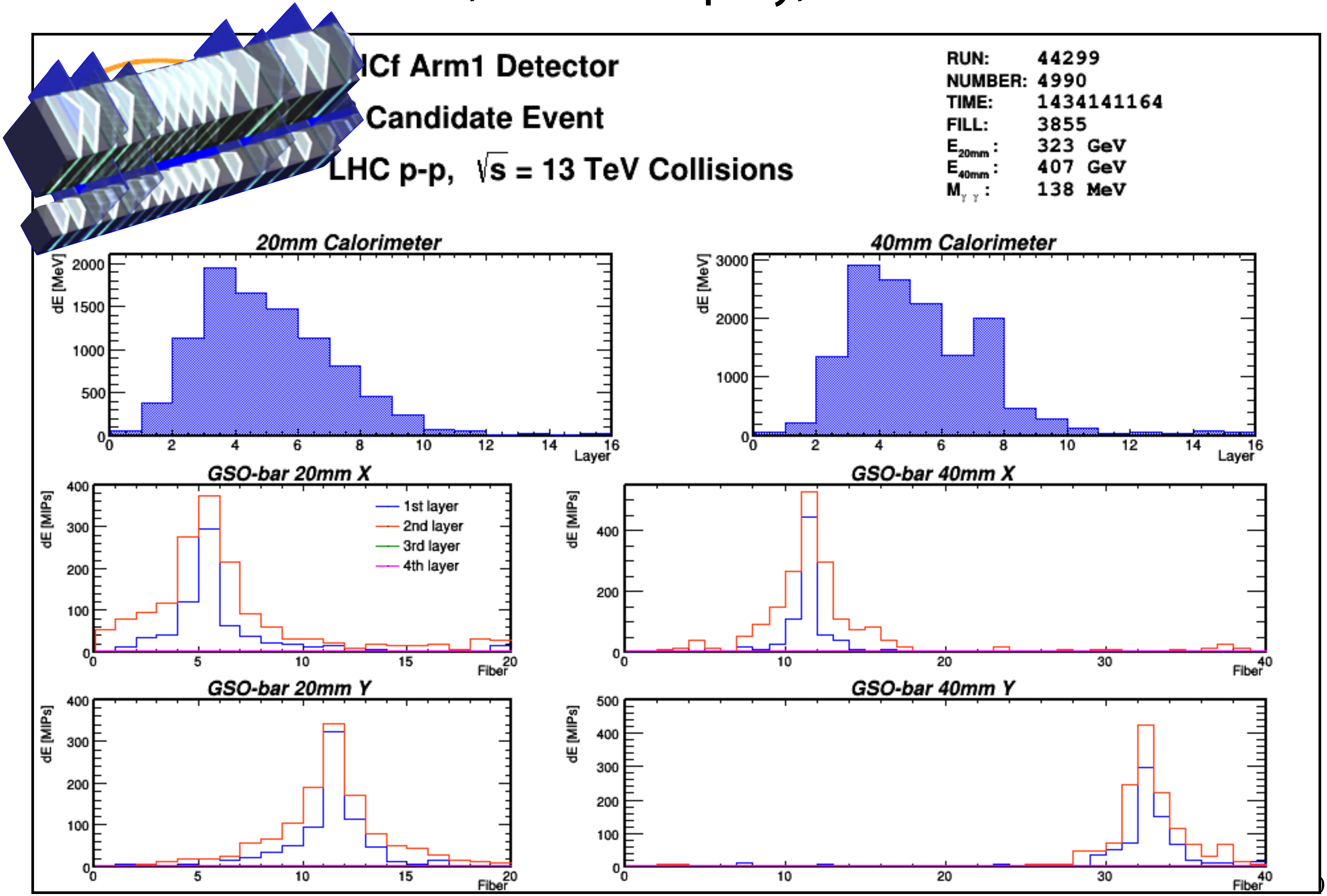
- Very-low luminosity special runs for LHCf
- 3 days for all physics program!!
  - No mistake is allowed…

LHCf control room (“barrack”)

13 TeV run, event display, π0 candidate

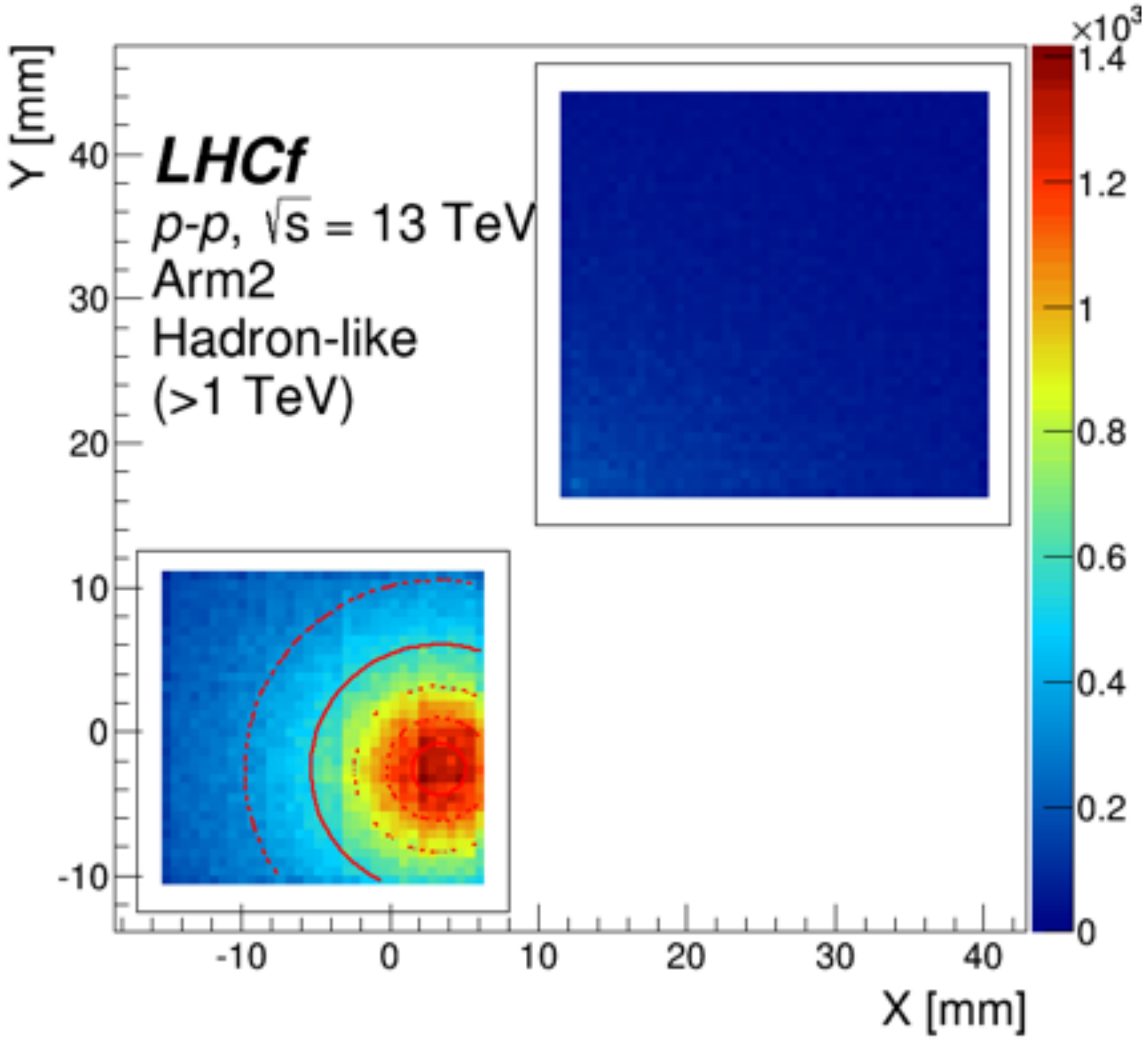


13 TeV run, event display, π0 candidate

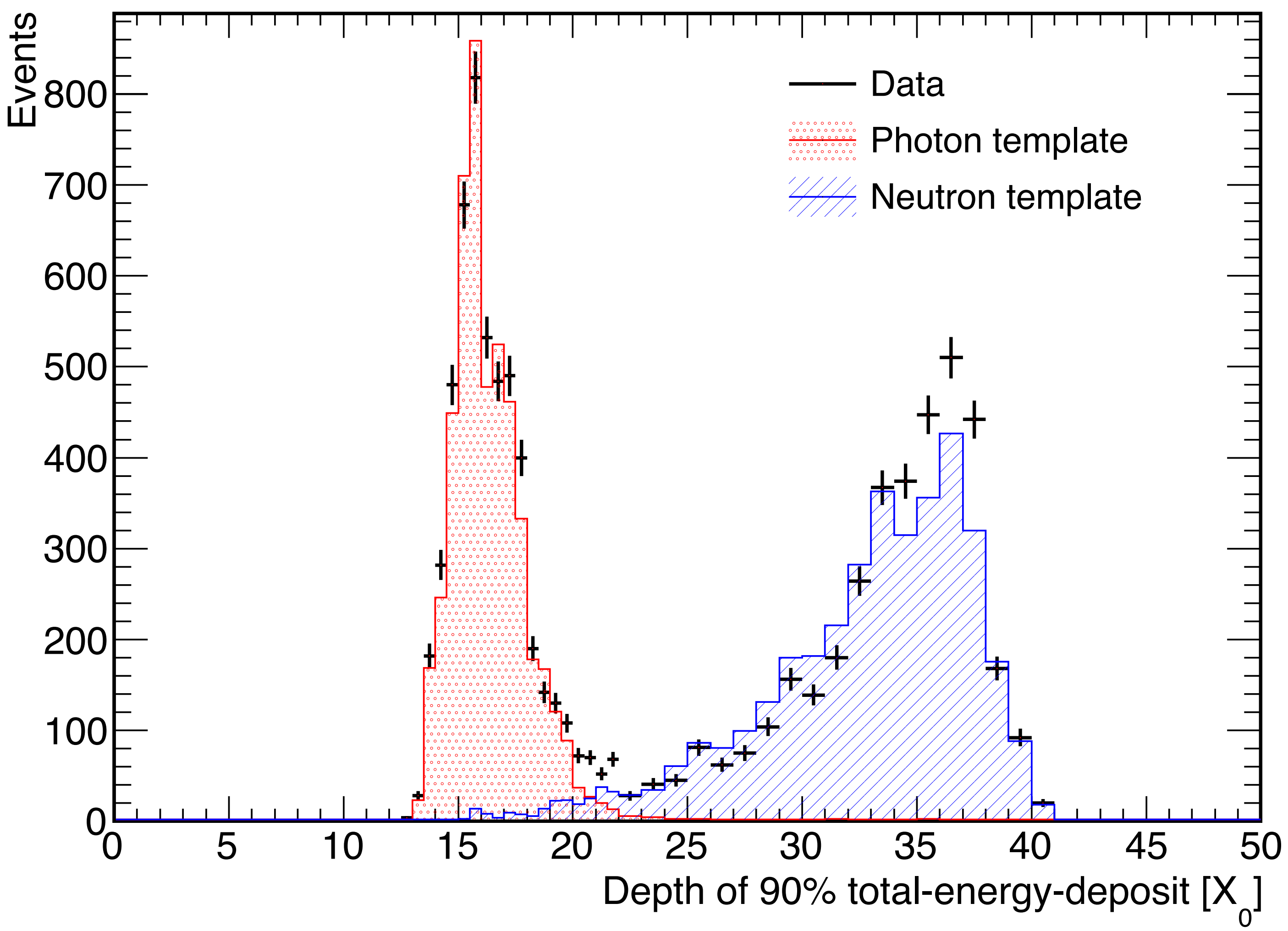


plots from 13TeV data…

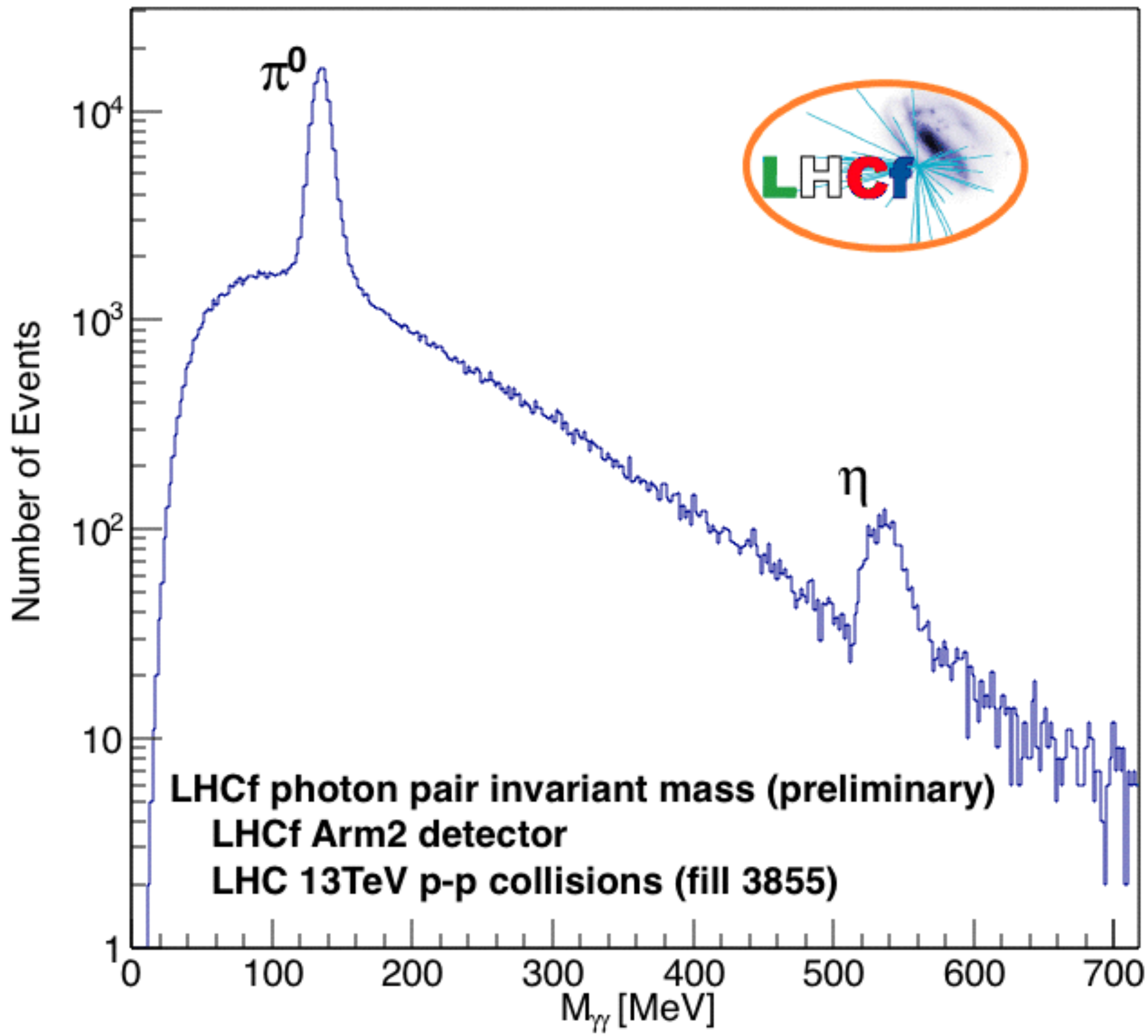
Beam center calculation



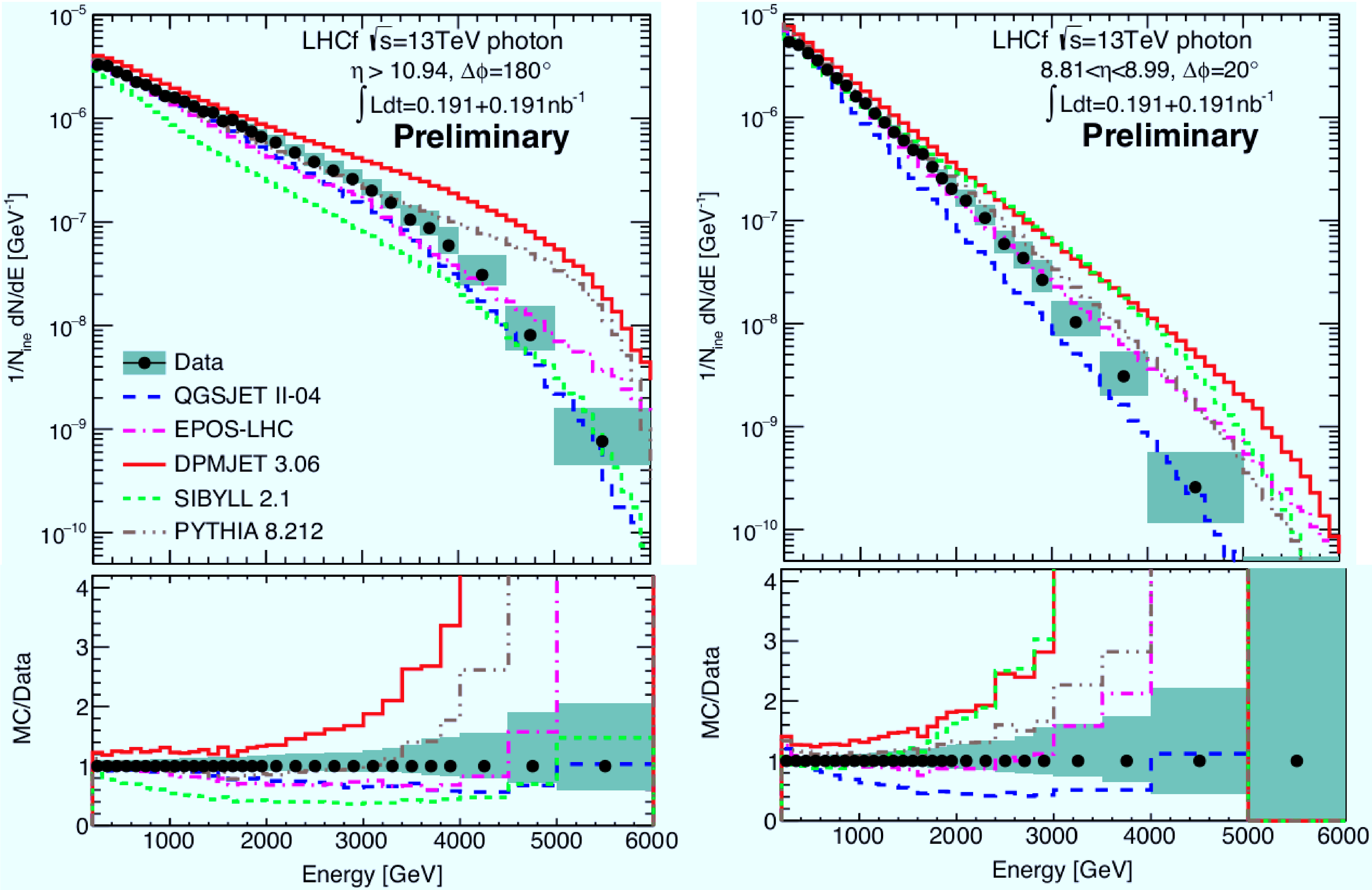
Photon/hadron separation



Energy scale monitoring during the operation : pi0 mass

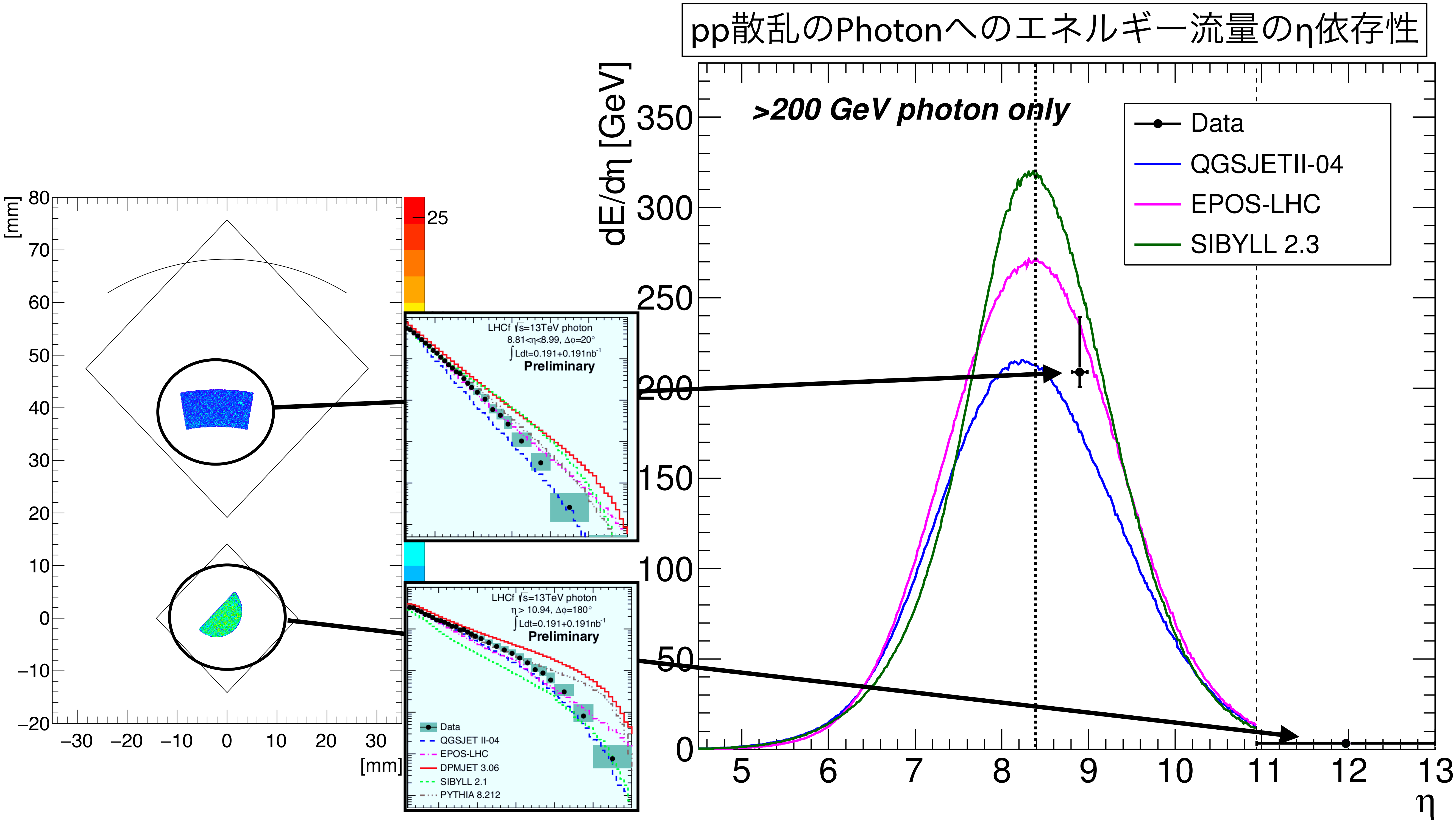


LHCf photon spectra @ √s=13 TeV



- DPMJET3, SIBYLL2.1などpre-LHCのモデルは測定値との乖離が激しい
- post-LHCのモデル(QGSJETII-04, EPOS-LHC)が測定値を良く再現

pp √s=13 TeV, Photon energy flow measurement



まとめ

- Large Hadron Collider (LHCf) experiment
  - LHCの超前方(η>8.4)でハドロン散乱で生成される中性粒子を測定
    - ガンマ、パイゼロ、中性子
  - 各ハドロン相互作用モデルの予測を比較、検証

- √s=0.9-13TeV / p-p, p-Pbでこれまでに測定を完了
  - 特に√s=13TeVでは放射線耐性を向上させた新型検出器で測定
  - これから
    - 11月にLHCでp-Pb ~√s=8 TeV
    - 来年５月 RHICで√s=510GeVで測定(RHICf)

- LHCfのデータを完全に再現するモデルはないものの、post-LHCと呼ばれるモデル群の方が再現性は確実によい

- 名古屋のLHCfグループはYMAPの活動に興味があります！